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THESIS

A SURVEY OF COMBAT MODELS
FOR USE IN
CARF VALUE GENERATION

by

Kevin J. Newland

March 1985

Thesis Advisor: Glenn F. Lindsay

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A Survey of Combat Models for use in CARF Value Generation

by

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I. INTRODUCTION

The Combat Active Replacement Factor (CARF) is a key logistics planning factor used in preparing budget submissions concerning Prepositioned War Reserve Stocks (PWRS). The manner in which this factor is currently generated is a matter of concern to Marine Corps logistics planners. Since the CARF is primarily an estimate of equipment losses in future conflicts, it is important to the Marine Corps that the basic methodology of CARF generation is based on sound reasoning. The current method of generation (which is explained in the following chapter), along with the subjective evaluation of some existing CARF values, often create doubt as to the accuracy of the factors produced.

This thesis will review the methods currently used for CARF generation and will suggest criteria by which several current combat models will be judged as to their ability to produce reasonable CARF estimates. Before proceeding with an explanation of the current system, we will examine the definition and usage of CARFs.

A. THE DEFINITION OF A REPLACEMENT FACTOR

The formal definition of a replacement factor is twofold. The first portion is stipulated by the Joint Chiefs of Staff (JCS) and is therefore uniformly applicable throughout DOD. The second portion is added to the JCS definition by the Marine Corps [Ref. 1]. The definition reads as follows:

> 1. Replacement Factors. A replacement factor is defined as: "the estimated percentage of equipment in use that will require replacement during a given period due to wear-out beyond repair, enemy action, abandonment, pilferage, and other causes, except catastrophes"

(JCS Pub.1). The Marine Corps expresses replacement factors as quantities required for a 30-day period. Replacement factors are identified in the item data file (IDF) and the Table of Authorized Material (TAM).

We note from the definition that the Marine Corps, not JCS, stipulated that replacement factors apply to quantities required for a 30-day period. Other services may choose a different time span as a basis for implementation of replacement factors. It should be noted that the replacement factor is a percentage by definition. Current Marine Corps practice expresses all replacement factors as four decimal place ratios (in the TAM and IDF) rather than percentages [Ref. 2]. We also observe the estimate of equipment requiring replacement applies to the "equipment in use". This implies that there may be equipment not being used such as items being held in reserve by a field commander or items held in inventory at a supply facility.

B. THE DEFINITION OF A COMBAT ACTIVE REPLACEMENT FACTOR (CARF)

The CARF is one of three different types of replacement factors used in the Marine Corps [Ref. 1]. A CARF is defined as follows:

1. Combat Active (CA). The combat active replacement factor will be applied for units during those periods when they are actually in active combat operations. A force in contact with the enemy is considered to be active combat. The combat active replacement factor reflects anticipated combat attrition of equipment, on a 30-day basis, incident to amphibious operations and other combat operations normal to the FMF. When applied to the density of equipment, the combat active replacement factor determines the amount of equipment which must be replaced each month to maintain the full T/E allowance. As described below, separate factors have been developed to recognize the variance in combat attrition, based on anticipated intensity of combat by geographic areas. The Commandant of the Marine Corps (Code I) establishes the period of support planned for each force and the applicable factors to be used in determination of requirements.

(a) Europe Intense (EI). This factor will be applied to determine the requirements for the forces

commited in the European Theater and will be restricted to the period of support during which intense combat is anticipated.

(b) Europe Sustained (ES). This factor will be applied to determine the requirements for the remaining period of support planned for forces committed in the European Theater.

(c) Worldwide Intense (WI). This factor will be applied to determine the requirements for forces committed to any geographic area other than Europe and will be restricted to the period of support during which intense combat is anticipated.

(d) Worldwide Sustained (WS). This factor will be applied to determine the requirements for the remaining period of support planned for forces committed to any geographic area other than Europe.

Before proceeding, four facts should be emphasized. First, the CARF is obviously a scenario dependent factor. Attrition of equipment will depend on both friendly and enemy force size, composition, disposition, training, tactics and lines of communication in a particular combat situation. This indicates that scenario holds a key role in CARF generation. Secondly, we note that the "equipment in use" will be considered for replacement within a replacement factor. The CARF restricts this by considering only the equipment of units which are in "contact with the enemy". The CARF also stipulates that attrition of equipment be restored to full Table of Equipment (T/E) allowance. Thirdly, due to the mission of the Marine Corps, both "amphibious and other combat operations" are to be included in the CARF. Lastly, four types of CARFs are defined by the Marine Corps: European and Worldwide scenarios, each with intense and sustained activity levels.

The Marine Corps currently publishes CARF values for most combat essential (type 1) items in classes II (individual and organizational equipment) and VII (major end items). CARF values are also published for items needed in special situations (type 2 and 3 items) which consist of construction materials, cold weather equipment and clothing, or other situational items (class II, IV and VII)

computed in a manner which will give an accurate CARF for these two purposes. To accomplish this, we can view the definitions of a replacement factor and a CARF in a somewhat broader sense. For example, a "force in contact with the enemy" should be any force which could be attrited due to enemy action. This would include transport convoys bound for the theater which are susceptible to the enemy air and submarine attack. The only causes of attrition not considered (by definition) would be catastrophic losses such as tidal waves, earthquakes, tornados, hurricanes, and similar events.

Considering this broad interpretation, the quantity of equipment attrited, QE_{ij}, can be subdivided into three main categories: loss in hands of combat units, loss of material in storage or maintenance (in theater) and loss of material in transit to the combat theater. Within each category of loss, causes of individual item losses may be assigned. Table 2 lists many such causes, although this list could easily be modified to fit a particular scenario [Ref. 8].

When we consider the broad interpretation of a "...force in contact....", the number of equipment type i, NE_i, seems an easy quantity to compute. The reference level used to compute NE_i is the Table of Equipment allowance of equipment type i as given in the definition of a CARF. For combat units, this is a relatively easy determination; however, for storage facilities in theater, or for equipment in transit, this is not trivial. These two categories must be assigned a reference level (like a T/E allowance) for the determination of NE_i. This could be done within a CARF determination system by assigning levels or by simulating quantities of equipment in storage or transit. These levels must be realistic to prevent inflation or deflation of NE_i; hence, the inverse effect on the CARF. For example, if we supposed QE = 60 for a thirty day period (e.g., 60 jeeps lost), and we

III. CRITERIA FOR CARF GENERATION

As we have seen, a CARF value is highly scenario dependent. Factors which influence the scenario , such as friendly (and enemy) force size, disposition, weapons mix and mode of operation (amphibious, offensive, defensive, etc.), all have a direct effect on a CARF value. In order to generate a CARF, we would like to analyze the factors that effect a CARF, within the scenario. Analysis of these factors will yield essential elements which might be considered in evaluating a CARF generation system. The elements, or criteria, fall into two categories: first, those criteria suggested by the definition of a CARF; and second, criteria suggested by practical constraints within the Marine Corps.

A. CRITERIA DERIVED FROM THE CARF DEFINITION

The definition of a CARF can be expressed in a brief mathematical model as follows:

$$CARF_i = \left(\sum_{j=1}^{n} QE_{ij} / NE_i \right) 100. \qquad (3.1)$$

The variable QE_{ij} is the quantity of equipment of type i which has been attrited by cause j over a thirty day period. The variable NE_i is the number of equipment type i in the area. Finally, i represents Marine Corps equipment while j represents the cause of equipment loss.

Before we analyze QE_{ij} and NE_i further, we stop to remember that we should view these variables with regard to the manner in which the CARF will be used. Since the CARF is used primarily for PWRS budget planning and amphibious lift capacity plans, the variables QE_{ij} and NE_i should be

for a probable Marine Corps scenario (such as the northern flank of NATO). (A smaller model would have the advantage of using less computer resources and could possibly be a Marine Corps in-house model.) The Marine Corps simply suffers from the size of WARRAMPS. Each Army study (which produces new WARFs) takes a full year to complete; thus, this model is not responsive to short term needs such as a change in scenario or a possible short term conflict.

Up to this point, we have discussed what a CARF is and how it is currently generated. We have also observed the process for the derivation of the foundation of the CARF, and the Army WARF. Weaknesses, along with strengths of the current CARF and WARF generation systems have been noted. In the following chapters, we will combine these points with other criteria to form a checklist of items which would be used to rate any system as to its ability to generate accurate CARF values.

Input of Marine Corps historical data is also a problem. The Army inputs its own historical data (along with exercises, tests etc.) into WARRAMPS. The Marine Corps may only input its data during the CARF determination process. The portion of the WARF which is the result of such Army data is indistinguishable at this point; accordingly, we cannot remove that portion of a WARF in order to add the effect of Marine Corps peculiar data. This means that Army historical data is intrinsically part of the CARF. This may be either good or bad, but the point remains we are uncertain what the effect is on the final CARF.

The CEM is deterministic in nature, and COSAGE is a Monte Carlo simulation. There are inherent problems with Monte Carlo simulations such as cost and time to run a model, since a great many replications must be used to attain an acceptable level of accuracy. Deterministic algorithms tend to be much less computer intensive than a Monte Carlo simulation.

A crucial problem to the Marine Corps is the unavoidable fact that WARRAMPS uses data prepared by Army personnel using Army scenarios in which representative Army weapons mixes and Army tactical doctrine are used. The Marine Corps would not normally expect to fight with Army tactical doctrine in an Army scenario with the same weapons mix the Army uses. Thus, in adopting the WARF, the Marine Corps is using a value which is not representative of its own doctrine. The current system lacks an amphibious phase; therefore, it is impossible for the Marine Corps to use a CARF for such an eventuality.

The size of the WARRAMP system is very large. This model has the ability to track several Army Corps in a large theater, probably Europe, for several months. The Marine Corps generally isn't concerned with such a large problem. A smaller model could easily produce more accurate results

In order to understand more thoroughly any problems which exist with the current CARF generation system, we should understand how the WARF (the basis of the CARF) is developed. A brief description of the methodology used to derive the WARF is given in Appendix B [Ref. 3: p. 25]. Readers unfamiliar with the WARF may desire to refer to Appendix B before proceeding.

E. SOME HAZARDS OF MARINE CORPS RELIANCE ON WARFS

Several problems occur from adopting the WARF as a basis for a CARF. Most of these problems arise due to the absence of Marine Corps input to the data base used in generating the WARF. We will start with a list of deficiencies of the WARF generation process as identified in a 1980 study. (1) The unit effectiveness is not degraded realistically when suffering high loss rates. (2) The Forward Edge of the Battle Area (FEBA) orientation may not represent the modern battlefield. (3) An inability to model fast tactical maneuver and complete breakthrough is probably due to the 12-hour time step used in Concepts Evaluation Model (CEM). (4) Pace and intensity of combat within the model is not responsive to new continuous warfare concepts. (5) Command, Control, Communication, and Intelligence (C3I) are not addressed adequately. [Ref. 3]

In addition to these shortcomings, the Combat Sample Generator (COSAGE) Model exhibits a distinct problem. COSAGE is a 24-hour division sized picture which is then taken by the Concepts Evaluation Model (CEM) and extrapolated to a 180-day theater level conflict. The problem here is obviously a large extrapolation of COSAGE data prone to distort the final WARF values in an unknown direction; therefore, the WARF accuracy is questionable.

As a final observation, we need to ask how CARF values for items which have no Army counterpart (and thus no WARF) are generated. There are several items in the Marine Corps inventory for which this does occur. When there are no Army items which are similar, CARF values are generated for these items in a manner similar to the previous CARF generation system (subjectively using military judgement). If there is a group of Army items (equipment) similar in nature (but not exactly the same), WARF values from the class of items in which it belongs are averaged and then applied as a CARF value to the mismatched Marine Corps item [Ref. 6]. This is another potential source of inaccuracy in the CARF since several items have no direct WARF value basis.

D. FACTORS CONTRIBUTING TO ADOPTION OF THE WARF AS THE BASIS FOR CARF GENERATION

The SRI study of September 1981 recognized four sound reasons for adopting the Army methodology as basis for a CARF determination process. These four reasons should be considered prior to adopting a new system in the future. First, the cost of implementing the system would be quite low since it would only involve the use of the previously derived Army WARF. The Marine Corps could access the WARF data at no additional cost except the software to run the system. Secondly, the methodology has already been developed by the Army; hence, no extra time or money would be spent trying to adopt another model (or develop a new model) to perform this function. Thirdly, it took little or no additional personnel to use the system as adopted by SRI since the actual derivation was completed by the Army. Lastly, the new system was considered to be more objective than the previous subjective system.

are the Sustained and Intense Replacement Factors. In a headquarters order [Ref. 7] on guidelines for a Replacement Factor Review Board, the Marine Corps appears to endorse this modified definition of the number of types of CARF values. This has not yet been reflected in any orders except Reference 7; accordingly, this policy is not yet widely used in the Marine Corps.

C. OBSERVATIONS REGARDING THE CURRENT SYSTEM

Adoption of SRI's CARF determination system created a minor conflict in the definition of a CARF. The current official definition indicates that CARF determines the amount of equipment to be replaced each (30-day) month to maintain full T/E allowance. SRI dropped this requirement from its CARF definition. It appears that SRI's CAAR definition is similar to the official definition; however, the CAAR speaks of attrition only, not replacement to any level. The SRI report further states that the CARF should represent the rate at which the Marine Corps will actually replace combat losses [Ref. 4: p.2]. This CARF will take into account shipping and budgetary constraints. The obvious question is how one could derive such shipping and budgetary constraints to be applied to a long-range logistics planning factor, since such constraints usually arise on short notice. Such constraints are not consistent with the JCS definition of replacement factors which consider only attrition due to the effects of the battle area. We can see that consideration of shipping capacity and budgetary constraints (other than attrition of shipping) is not pertinent to CARF generation. The reader should also be aware that the CARF values originally derived by the SRI process in 1981, were a result of the P-86 WARF study (completed in 1981). These CARF values have not significantly changed since then, with the exception of new items of equipment.

> Combat Active Attrition Rate (CAAR)*--The estimated percentage of the in-use amount of an item that is expected to be lost during a given 30-day period of active combat as the result of combat attrition.

According to the SRI report, the only difference between a CARF and a CAAR is that a CARF has been reviewed and approved for publication. In the report, the CARF is defined as follows:

> Combat Active Replacement Factor (CARF)*--An approved planning factor used principally for material requirements determination which states the percentage of the in-use amount of an item that is expected to require replacement during a given 30-day period of active combat as the result of combat attrition.

There are two subtle differences between the Marine Corps and SRI definitions. First the SRI definition doesn't require replacement of equipment to the T/E allowance level. Secondly, the CARF defined by SRI was intended to allow adjustments to the CAAR for several reasons, as noted in this excerpt [Ref. 4: p.2].

> The CAAR serves as an estimate of combat losses while the CARF represents the rate at which the Marine Corps will plan (i.e., compute requirements) to actually replace combat losses. This distinction recognizes the possibility that shipping constraints, budget constraints, and other considerations may preclude the use of CARFs that would call for the replacement of all equipment losses.

The definition of a CAAR and CARF offered by SRI have not been adopted by the Marine Corps for general use. The CARF generation system proposed by SRI was adopted [Ref. 5] and is described briefly in Appendix A.

We should also note that the user's manual for the current Marine Corps CARF Determination System [Ref. 6] states that only two types of CARF are used within the system (vice four by Marine Corps definition). These two

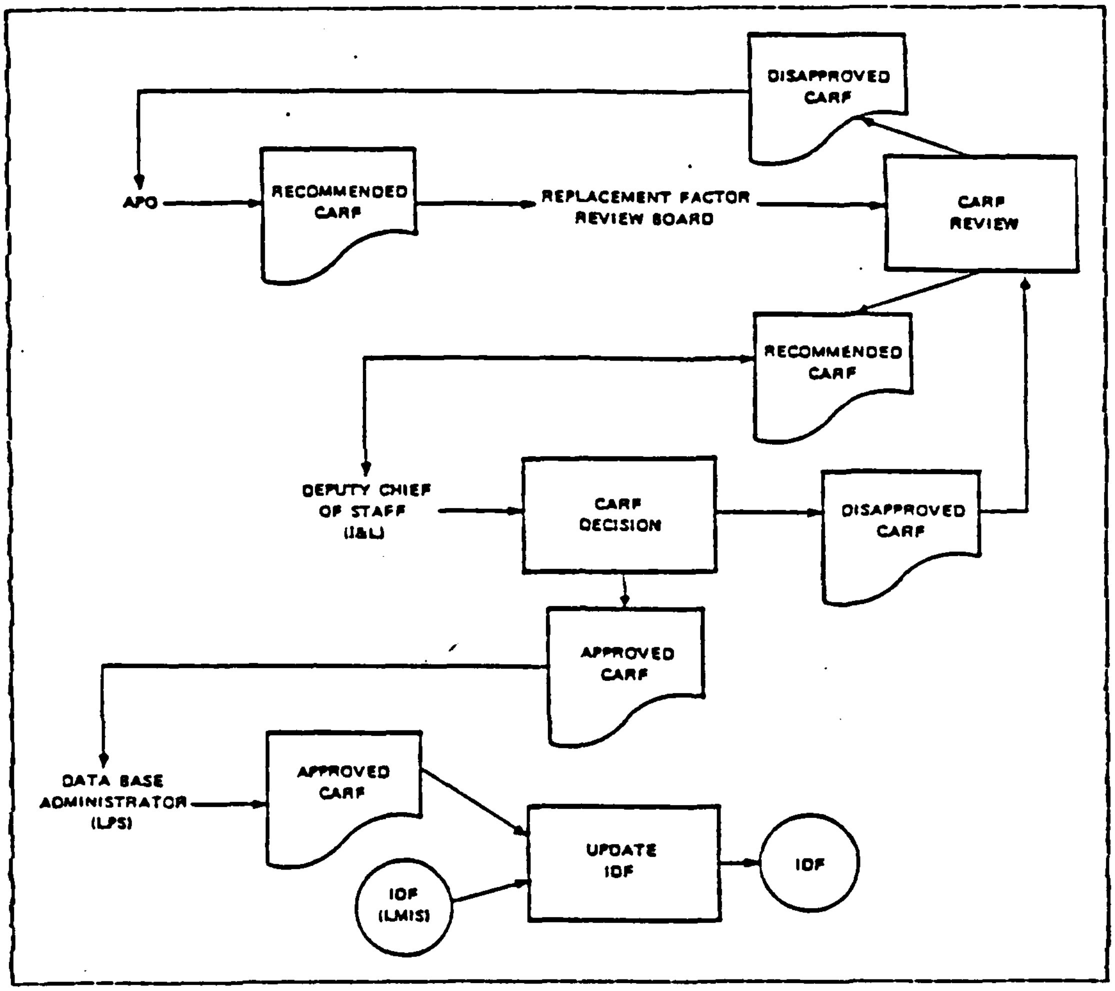


Figure 2.1 Overview of the Previous CARF Generation System

B. THE CURRENT CARF GENERATION SYSTEM

Currently, the primary methodology of CARF generation is the utilization of U.S. Army Wartime Active Replacement Factors (WARFs). This methodology was implemented subsequent to a study completed by SRI International (SRI) [Ref. 4]. SRI divided the Marine Corps definition of a CARF into two segments: the Combat Active Attrition Rate (CAAR) and the Combat Active Replacement Factor (CARF) [Ref. 4: p. 2]. The CAAR is defined as follows:

II. THE CARF GENERATION SYSTEM TODAY

The previous and current CARF generation systems will be described in this chapter in order to provide a brief history of CARF generation and to identify several problems which existed in the previous system or currently exist in today's process.

A. THE PREVIOUS METHOD OF CARF GENERATION

Prior to July of 1981, the commodity branches within the Materiel Division of the Installations and Logistics branch of HQMC were responsible for the origination of CARF values for new items entering the inventory. The individual Acquisition Project Officers (APO) generally bore this responsibility. The APOs were to consider such factors as engineering estimates, test results, research studies, CARFs for like items, factors assigned by other branches of DOD and their own "military judgment". The APO was also responsible for initiating changes to existing CARF values. The APO submitted his proposals to the Replacement Factor Review Board.

The Review Board was responsible for approval of CARF values for new items as well as the revision of established CARF values as they deemed necessary. The Board's primary tools were the collective judgment and experience of its members. The Review Board's results were forwarded to the Deputy Chief of Staff for Installation and Logistics for action. Approved CARFs were recorded in the Item Data File (IDF) and periodically published in the Table of Authorized Material (TAM). This process is illustrated in Figure 2.1 [Ref. 3].

their aptitude for generating CARF values. Prior to undertaking such an evaluation, two tasks will be performed. First, the history and current methodology of CARF generation will be described. Discussion of current and previous methods will lead to a list of strengths and weaknesses of the current system. With this list as a basis, we will proceed to the second task which is the development of criteria by which a CARF generation system (i.e. a combat model) should be evaluated. In order to arrive at suitable criteria, we need to keep in mind the purposes which require the use of a CARF, the range of items for which a CARF is computed, and the types of combat scenarios which will require CARF generation.

From the criteria derived above, a scoreboard can be constructed by which a combat model may be evaluated for the specific purposes of examining its applicability to CARF generation.

Table 1

Users and Uses of CARF Products (cont'd)

Users	Uses	Processes	Files
Headquarters, FMF:			
Force supply office/G-4	Validation of WMR/WRMR (Mount-out)	Manual review	Mount-out listings (furnished by Albany)
	Review of CARFs	Manual review	IDF extracts
G-5 section	Computation of lift requirements	MAGTF Lift model	MAGTF Lift model data bases
FMF subordinate commands:			
Division supply office Wing supply office FSSG	Review mount-out requirements	Manual review	Mount-out tapes/listings
FSSG (SMUs)	Update and maintain mount-out requirements	SASSY	General Account Balance file; Mount-out tapes

Note: Table 1 is taken from Reference 3 .

TABLE 1

Users and Uses of CARF Products

Users	Uses	Processes	Files
HQMC (I&L)			
Commodity branches (Acquisition project Officers-LMC, LME, LMA, LMW)	Computation of inventory objectives (Post D-day consumption)	P20 Process (LMIS)	IDF/EAF
Materiel plans and policy branch (LMP) and Programs and financial management branch (LPF)	Preparation of WMR/WRMR budgets and shopping lists	P20 Process; Miscellaneous special purpose programs (manual and automated)	IDF/EAF; Tape ex -acts from War reserve subsystem; Output from MUMMS stratification programs
Joint matters/strategic mobility branch (LPS)	Determination of JOPS and JSCP data	MAGTF Lift model	MAGTF Lift model data bases
Plans and policies branch (LPP)	Logistics planning	MAGTF Lift model	MAGTF Lift model data bases
Systems branch (LPS)	Providing to HQMC staff ad hoc retrieval of CARFs and CARF products	Special programs	IDF
MCLB, Albany	Computation of WMR/WRMR	War reserve subsystem (SS-11)	IDF/EAF
	Computation of WMR/WRMR deficiencies (requirements minus assets on hand)	Stratification	War reserve files (SS-11); Master inventory file (SS-03)

[Refs. 1,2]. Accordingly, CARFs are published for a large number of items which span the spectrum of equipment types used within the Marine Corps. It would be difficult, within one combat model, to generate CARF values for all these items. For many of these items, CARF values may be generated in a manner indirectly related to the combat model. Historical, exercise, or usage data may be possible sources for generating CARF values for items not considered by the combat model.

C. THE CURRENT APPLICATION OF CARFS

The current use of CARF values bears important budgetary implications in two of its current roles. The first role is the direct use of CARF values in computation of budget dollars required for purchase of Prepositioned War Reserve Stocks (PWRS). This key role of the CARF insures its effect on the multi-million dollar portion of the yearly Marine Corps budget which is devoted to the procurement of PWRS. Its second major role is as a key factor in the Marine Air Ground Task Force (MAGTF) lift model. This model is used in logistical planning for Marine Corps and joint service operations. This model also influences shipping requirements being planned for Marine Corps involvement in national contingency plans. These two roles are of such importance that the accuracy of CARF values currently generated should be examined. Other uses of the CARF exist at Headquarters Marine Corps, Marine logistics organizations, and throughout the Fleet Marine Force (FMF). Table 1 lists several current uses of CARF values in the Marine Corps.

D. THE PURPOSE OF THIS STUDY

The primary purpose of this study is the evaluation of several currently available combat models with respect to

TABLE 2

Category and Cause of Attrition

Cause of Loss	Category of Loss		
	Material in Hands of Combat Units	Material in Storage or Maintenance in Theater	Material in Transit
Direct Fire	XXXXX		
Area Fire	XXXXX	XXXXX	
Rocket Launcher Fire	XXXXX	XXXXX	
Air attack	XXXXX	XXXXX	XXXXX
Damaged and Abandonment	XXXXX		
Land Mines	XXXXX		
Mobility Failure and Abandonment	XXXXX		
In Maint. and Abandonment	XXXXX		
Accident	XXXXX	XXXXX	XXXXX
Wear-out	XXXXX	XXXXX	
Missiles	XXXXX	XXXXX	XXXXX
Sabotage and Guerilla Activity	XXXXX	XXXXX	XXXXX
Pilferage		XXXXX	XXXXX
Reallocation to Allies or other Service		XXXXX	XXXXX
Sea attack			XXXXX

determined a T/E level of 45 jeeps for combat units and 5 jeeps for theater storage and in transit, then the CARF=120%

((60/(45+5))100). If we had included another 100 jeeps which were shipped on the 25th day of the period instead of the 5 jeeps for theater storage and in transit, we would have a CARF=40%, resulting in a deflated CARF value.

B. CRITERIA GENERATED FROM PRACTICAL CONSTRAINTS

Due to the size and mission of the Marine Corps, several practical constraints on any CARF generation system need to be recognized. First of all, the Marine Corps cannot easily spare personnel to operate such a system. Any new system needs to be as streamlined and compact as possible to minimize the number of personnel required for operation. Secondly, the data for such a system should come primarily from existing sources, such as data generated and maintained by CNA or the Army. This will aid in reducing the system manpower requirement. Thirdly, any Marine Corps sponsored CARF generation system should be compatible with the computer assets at Quantico or the Installations and Logistics section of HQMC.

These three practical restraints can be met by specifying three characteristics which contribute to reduction of system size. First, associating the loss of a major end item to the loss of its components or physically related items enable us to reduce the data base size. For example, if we designate personal equipment (rifles, 782 gear, clothing, etc.) as a component of the individual Marine, loss of one Marine will indicate loss of his personal equipment. Similarly, loss of a tank will indicate the loss of all components (such as its .50-caliber machine-gun) which belong to the tank. Secondly, analysis of the types of items requiring a CARF should reduce the number of items in the actual data base for the CARF generation system. Association of losses, and consideration of only high dollar

value items (which are important to budget planning or amphibious lift planning) will enable us to restrict the number of items considered. The fewer items considered, the smaller the overall system and fewer operators needed. Lastly, the scenarios for which a CARF is to be computed should be restricted to that scenario which is considered to be "worst-case" for the Marine Corps. Since the CARF is used in budget planning, we need to consider the "worst case" scenario in a strategic (area of the world in which the conflict may occur) vice a tactical (within the theater of operations) connotation. If a set of CARF values is prepared for this scenario, the budget planning which results from these CARF values would be ample for any other world crisis if indeed the "worst-case" scenario was correct. Using the CARF for more routine purposes in the FMF could be supplemented or replaced by usage data or exercise history data, thereby reducing the need for CARF values for lesser scenarios (i.e., a worldwide CARF value). These three characteristics will be helpful in keeping the size of any CARF generation system small enough to be used by the Marine Corps on an in-house basis.

We have identified several problems with the current system in the previous chapter and have discussed several criteria to be applied to any future CARF generation system in this chapter. The following chapter will consider the characteristics of combat models which will be most helpful in evaluating current models for CARF generation.

IV. MODEL ATTRIBUTES DESIRED FOR CARF GENERATION

This chapter will concentrate on explaining several attributes which we desire to see in a model used to generate CARF values. We will initially investigate several general qualities which are intrinsic in a fundamentally sound combat model. Highlights of modeling technologies will be discussed to assess their effect on the attributes and qualities desired in a combat model. The later portion of the chapter will be dedicated to deriving a Measure of Effectiveness (MOE) which will be useful in comparing existing combat models. We will use the attributes and MOE in Chapter V to survey several different combat models.

A. ATTRIBUTES DESIRED IN A COMBAT MODEL

Combat modeling is not precise by nature. The assumptions involved and the volatile, unpredictable nature of combat indictate that combat models will not be a precise (precise in the sense an accounting model is precise in predicting future monetary outcomes) prediction of future conflict. This lack of a precise mathematical representation of combat has led to a colorful name for this issue: the "Squishy Problem" [Refs. 9,10]. In a report to Congress, the General Accounting Office (GAO) has outlined several attributes which are desirable of any computer model used for contributing to the budget process [Ref. 10: p. 3]. These attributes assist the decision maker in determining how useful the information from a "policy assisting model" is for his purpose. Such attributes are somewhat subjective in nature; however, they are useful to us as criteria by which we can evaluate combat models for the purpose of CARF generation. The attributes are as follows:

Our purpose is...to emphasize the need for ensuring that policy assisting models used in Defense Decision are:

* Transparent so that a decisionmaker can understand and use the model as an extension of his/her own judgment. Implying that
  --Assumptions are clearly described and held to manageable proportions, and
  --The deductive process leading to the model's assertions is clear (transparent).

* Appraised so that a decisionmaker can be assured that
  --The model is mathematically correct,
  --The part of the model that is science matches the real world, and
  --The model uses empirically valid data.

* Consistent so that communication is facilitated throughout the decisionmaking hierarchy. Implying that
  --Problems are analyzed in the same context, and
  --Differing viewpoints can be discussed on the basis of specific assumptions.

Since the computation of CAEF values are based on attrition of equipment, we need to understand the two basic approaches to attrition modeling: aggregated and detailed. The aggregated method commonly uses firepower scores to determine an overall index for a unit's strength. The ratio of the indices for a red and a blue force is called the force ratio. This "lumps together" into one number the strength of several weapons which is then used to determine the number of units attrited in an enemy force. An example of this process using tanks is shown in Figure 4.1 [Ref. 10: p. 55]. The problem with aggregation is the decision to disaggregate the firepower index after attrition into its separate components. This is not a very "transparent" or mathematically sound concept. GAO states [Ref. 10: p. 54] the problem with aggregation as follows:

> Firepower scores are commonly used as a basis for aggregation. The basic problem in developing an aggregation scheme is a linear weighting problem (e.g., how many rifles are equivalent to a tank, a flamethrower, or an aircraft?). Further, the linear addition of firepower scores does not reflect the generally accepted principle that the whole of a force is worth more than the sum of its parts--e.g., two tanks operating in unison should be more effective than if they were employed on independent missions.

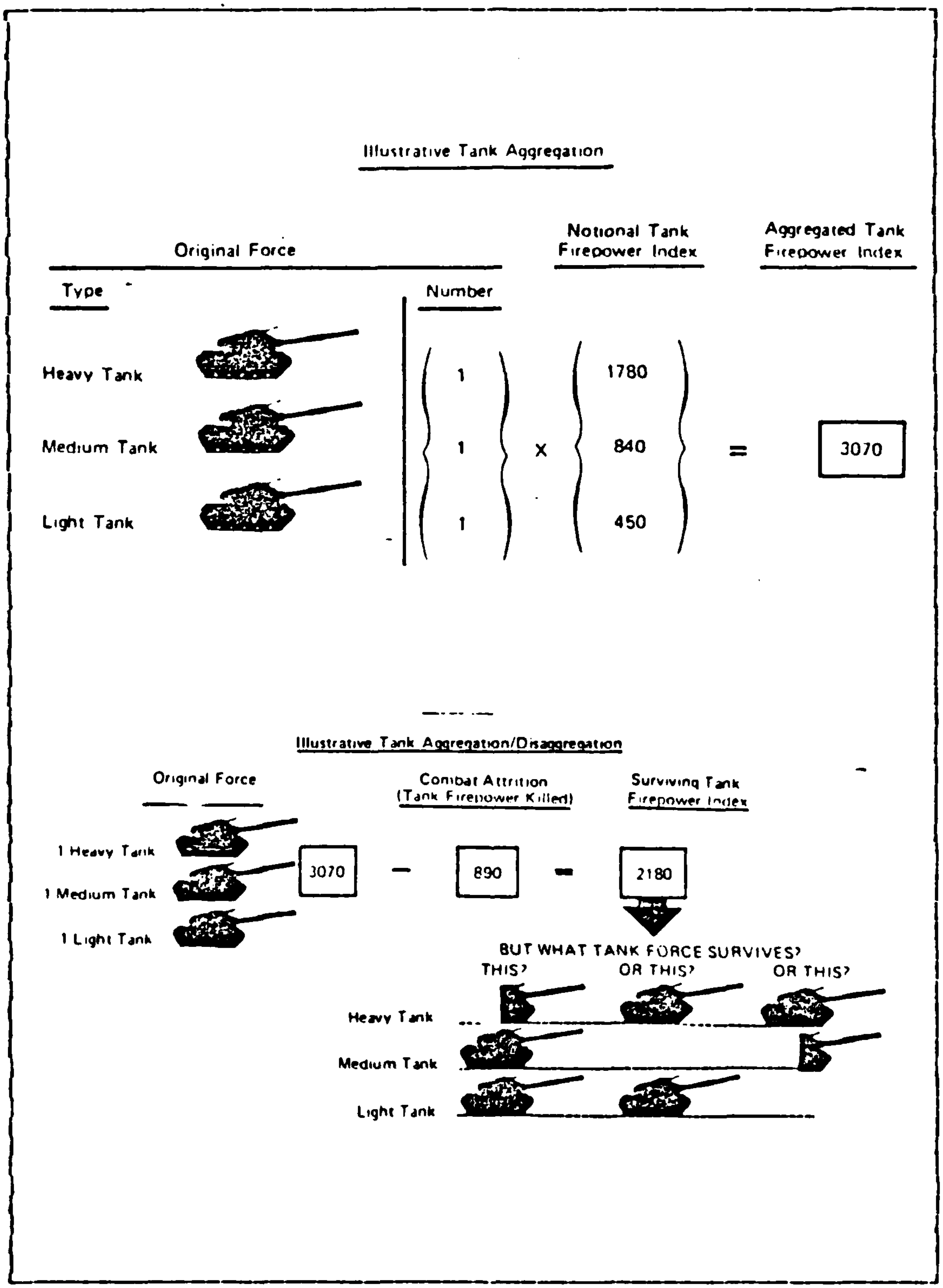


Figure 4.1 The Problem Posed by Aggregation

Detailed models for attrition tend to predict killer-victim relationships based on weapon performance factors, acquisition parameters, line of flight data, number of weapons by type and data on force employment. These factors may involve subjective input, but the relationship which links these inputs to the attrition of a particular weapon is usually more transparent and consistent than the aggregated model. A detailed model of attrition considers the loss of individual weapons. An aggregated model of attrition considers the sum of the losses from a group of similar weapons (as done in using a firepower index). GAO stated the difference between the two model types as follows:

> The point is that detailed models make judgment explicit (and hopefully transparent). The decisionmaker can control target engagement priorities, open fire ranges, etc. Critical parameters can be modified to reflect changes in tactics and battle doctrine.
> This is not so for aggregated models. The firepower index--keystone of the aggregated models--is predicated on a highly stylized interpretation of combat. Its derivation rests on judgments about tactics, open fire ranges, rates of fire, and the distribution of that fire (e.g., the percentage of tank firings directed at armor, mechanized personnel carriers, and foot infantry), etc. In other words, both the structure (aggregation scheme) and input data (firepower potential scores) for an aggregated model contain critical assumptions-- assumptions that may be methodologicly and intuitively inappropriate for a particular analysis.
> Recall our concern for model transparency.

These two methods of attrition modeling may be used in a Monte Carlo simulation model, an analytical model or a mixed model. The hazards and benefits of each of these types of models need illumination. The simulation tends to provide a high level of detail about combat processes and is therefore considered more credible by many people [Ref. 11: p. 16]. Because of the use of statistical sampling techniques, many consider these models to be a more accurate portrayal of combat. This level of detail carries a high price tag. Model development for a Monte Carlo simulation may take five

to ten man-years of effort to fully develop [Ref. 12]. These models tend to be very expensive to run since one needs 10-100 replications of the simulation to achieve statistical stability. Table 3 lists some disadvantages of a Monte Carlo simulation of combat [Ref. 11: p. 19].

TABLE 3

Some Disadvantages of Monte Carlo Simulation of Combat

A. Costly to build
B. Costly to run
C. Costly to maintain
D. Lack of flexibility for change
E. Essentially impossible to perform sensitivity and other parametric studies.

Analytical models, whether stochastic or deterministic, are distinguished as being more abstract than Monte Carlo simulations. Good analytical models are "usually quite abstract, poor in the number of variables explicitly considered, but rich in ease of manipulation and clarity of insight" [Ref. 11: p. 10]. The primary advantage of an analytical model is the smaller amount of time needed to run the model on a computer. This facilitates sensitivity and parametric analysis on the resulting data. A secondary advantage of the analytical model is transparency. The basic structure and assumptions of analytical models tend to be easily understood in comparison to Monte Carlo simulations. The analytical model tends to fulfill our attributes of transparency, appraisal and consistency better than do simulations; however, the degree of simplicity in analytical models may be a serious detractor. A hybrid analytical-simulation model may afford a better mix of transparency, consistency, appraisal and sophistication. [Ref. 11]

Other criteria which will influence our model selection for generation of CARF values are practical restraints due to the structure of the Marine Corps. The model should be expected to handle a heavily reinforced Marine Corps division, known as a Marine Amphibious Force (MAF). Since the Marine Corps normally fights as an integrated air-ground team, we would expect air power, both helicopter and fixed wing, to be modeled. The division size model seems to be a point of transition in current combat models. A division is not so large that it cannot be modeled with a high resolution model allowing detailed attrition modeling. If the unit size were any larger, we would transition to a theater level model in which the resolution is generally low and attrition modeling becomes less transparent.

Due to the amphibious mission which is unique to the Marine Corps, it would be an asset for any model to possess the ability to model at least the amphibious phase of a scenario. Although this is not necessarily crucial, the modeling of this type of combat does pose a significantly different attrition process than land combat. Amphibious landing attrition estimates should be part of a CARF value when dictated by the scenario. Terrain and weather are also important factors to consider in a model. These two factors are critical in actual combat and can account for large variations in the outcome of battle; hence, a model incorporating weather and terrain considerations would be considered a stronger, more accurate (consistent) model.

In this chapter, we have considered many attributes of a model which we use to produce CARF values. These attributes may be used as criteria by which we can screen current combat models. Such criteria are subjective in nature and are not easily measured except for a simple yes or no answer. We now consider a measureable criterion by which we can rate models as to their cost of operation.

B. A MEASURE OF EFFECTIVENESS (MOE) FOR EXISTING COMBAT MODELS

Existing combat models generally have been documented to the extent that several objective measures of the models are known. For the purposes of screening a combat model for CARF value generation, we will take advantage of such measures common to most documented models. These measures are generally expressed in units of time. Time to acquire a data base, time to structure a data base, playing time per cycle, CPU time per model cycle, learning time (for war games) and output analysis time, are all examples of measures common among existing models [Ref. 13]. We would be able to measure the effectiveness of a model in terms of time economy by summing the amount of time required to obtain results for one model cycle. The different units of time used in measuring manpower and CPU utilization are a hindrance. If we were to assign a cost per man-month and a cost per minute of CPU time, we could aggregate the measures (time required for data base analysis and preparation,output analysis and evaluation, and CPU time) of each model into a total cost per cycle of each model under evaluation. To keep this comparison on an equivalent basis, we can assign a model cycle to be a day (24 hours) of modeled combat. Our comparison now yields the total cost (in dollars) for the first day of combat for each combat model being considered for CARF generation. Figure 4.2 gives a graphic display of this method of deriving a measure of combat model cost effectiveness. The MOE illustrated in Figure 4.2 enables us to compare the cost of the first day of combat for each model surveyed. We consider such factors as the cost of CPU time, the cost of manpower to acquire and prepare a data base, and the cost of manpower for output analysis and evaluation. Figure 4.2 forms the basis for the first segment of our cost comparison.

Man-Months required for data base acquisition and preparation	X	Cost per Man-Month	=	$
CPU Time in Minutes for a 24-Hour Combat Day	X	Cost per Minute	=	$ per Combat Day
Man-Months required for Output analysis and evaluation	X	Cost per Man-Month	=	$
				=================

Measure of Effectiveness = Total Cost for First Day of Modeled Combat

Figure 4.2 **Measure of Effectiveness for Comparison of Combat Models.**

The last segment of our cost comparison uses an approximate daily cost of operation for each model. We know that the costs of operating the model for each successive day of combat will decrease since less time is generally required for data base acquisition and preparation. In general, a closed-loop (systemic) model requires input of the decision logic before the first day of model operation; hence, the cost of decision logic input is paid before the model's first day of operation. The man-in-the-loop model bears the cost of decision logic input during operation of the model since the players are responsible for input of decision logic. We can compare the daily operational cost of each model, minus the cost of data base acquisition, preparation and analysis. Adding the daily CPU, player, and operator costs (as applicable) for each model gives us a daily operational cost. We will interpret the daily operational cost as the cost to operate the model for 24-hours of simulated combat within one day. This will require man-in-the-loop

(real-time) models to operate on a 24-hour basis (shifts of players may be needed). Comparison of the daily operational cost will be an approximate measure of how rapidly model operation costs accumulate. Since the CARF is defined to measure attrition over thirty days, we will compare the rates of operational cost accumulation over a 30-day period of simulated combat for each model.

Remembering the critique of the current CARF generation system from Chapter II and the criteria described in Chapter III, we will be able to proceed to Chapter V for a comparison of different combat models for generating CARF estimates. Note that we are not comparing model effectiveness (or quality); rather, we are comparing models in order to ascertain their suitability for the purpose of generating CARF values. Careful use of the criteria described so far will yield one or more combat models which exhibit acceptable performance with regard to the derived criteria.

V. COMPARISON OF SELECTED COMBAT MODELS

This chapter will compare several currently used combat models using the criteria discussed in previous chapters. A brief review of the evaluating criteria is appropriate at this point. Chapter III mentioned two important criteria. First, the cause of attrition to be considered in a combat model is outlined in Table 2 . Most models will not be capable of accommodating all causes of attrition, but Table 2 is a guideline for the type of attrition to be reflected by a CARF. Secondly, we mentioned three practical restraints which are indigenous to the Marine Corps. These are:

(1) to minimize additional manpower required for model operation,

(2) to use data from existing Marine Corps sources, and

(3) to be compatible with existing Marine Corps computer (hardware) resources.

In Chapter IV, we were able to derive six model attributes to be used as evaluation criteria. (1) Model assumptions and deductive processes should be clearly documented and understood in order to give a transparent quality to the model. (2) The model should be appraised for mathematical correctness and a realistic match of science and the real world. (3) The model should be consistent in appraising the scenario being modeled. (4) The process used to model attrition within the model should be detailed in nature. Aggregated attrition process tends toward inconsistency and opacity. (5) The modeling capabilities preferred for a CARF generation system are to model:

(a) a Marine Corps Amphibious Force (MAF),

(b) aviation forces (fixed wing and helicopter),

(c) terrain and weather factors, and

(d) the amphibious assault phase of a combat scenario.

(6) Figure 4.2 illustrated a method of comparing the operating costs of the first day of combat of the combat models being evaluated. Comparison of daily operational costs were also discussed.

Five combat models will be evaluated for their suitability to generate CARF values. The combat models to be evaluated are:

(1) Vector-2,

(2) The Amphibious Warfare Model (AWM),

(3) Combat Sample Generator (COSAGE),

(4) Division Map Exercise (DIME), and

(5) Corps/Division Evaluation Model (CORDIVEM).

These models were chosen because each is capable of modeling combat for a MAF. Points of contact for obtaining further information pertaining to these models are available in Appendix C. The evaluation of the five models will proceed in order of the evaluating criteria reviewed above.

A. THE CAUSES OF ATTRITION CONSIDERED BY THE MODEL

Table 4 illustrates the type of attrition, by cause and category, considered in each model. Most of the five models portray the same types of attrition, except the Amphibious Warfare Model (AWM). As part of its amphibious assault module, it has a limited ability to model loss of material in transit during the amphibious phase of the operation due to cruise missile, artillery and sea mines [Ref. 14: p. 19]. The AWM's capacity to consider loss of materials in transit is unique among the five models. Four of the five models have limited capability to model attrition of equipment in storage and maintenance. The ability to model this type of attrition depends upon the depth of the sectors designated for the major units (division) in the model. The depth

cost comparison in Figure 5.3 also disregards the cost of players in a war game. The closed-loop models avoid this cost and, when viewed from this perspective, are more economical. A model such as CORDIVEM requires six months of player training and apprenticeship* for fourteen players [Ref. 26]. The cost of fourteen players, even for one day, is large. Training of one group of players would cost about $13,333.32 for DIME (4 players) and $46,666.62 for CORDIVEM (14 players). Unless the model has an additional mission of tactical training, the expense may not be justified. When we add the cost of training one group (or shift) of players to the last column of Figure 5.3, we have the total cost for the first day (24-hours) of modeled combat including player training cost for one group of players. The second column of Table 5 illustrates this cost by model.

If we compare the daily operational costs in the manner discussed in Chapter IV, we will be able to graphically compare the daily operational cost of each model for a 30-day period. For our example, we can use the cost of the first day of combat as the y-intercept and the daily operational cost as the slope for each of the models. We need to consider the salaries of each person needed to continuously operate each model and the CPU time required for a 24-hour day of simulated combat to arrive at a daily operational cost for each model. This is illustrated in Table 6 . We note in Table 6 that a closed-loop model, like Vector-2, takes very little time to complete a day of simulated combat. We have implicitly assumed in our comparison that running a day of combat in a closed-loop model requires one working day. Therefore, we have over-estimated the cost of daily operation to some extent since a closed-loop model

*CORDIVEM requires about 4 weeks of training followed by a 5 month apprenticeship period before the players are considered fully trained.

<table>
<tr><th></th><th>Data Base Acquisition</th><th>Data Base Formatting</th><th>CPU Time</th><th>Player Learning Time</th><th>Data Analysis and Evaluation</th><th>Cycle Length</th></tr>
<tr><td>Vector-2</td><td colspan="2">6 man-months</td><td>11 seconds per cycle</td><td>N/A</td><td>1/2 man-month</td><td>24 hrs.</td></tr>
<tr><td>AWM</td><td>3 man-months</td><td>1/4 man-months</td><td>10 mins. per cycle</td><td>N/A</td><td>1/4 man-month</td><td>48 hrs.</td></tr>
<tr><td>COSAGE</td><td>10 man-months</td><td>20 man-months</td><td>20 to 180 mins. per cycle</td><td>N/A</td><td>10 man-months</td><td>24 hrs.</td></tr>
<tr><td>DIME</td><td colspan="2">3 1/2 man-months</td><td>10 mins. per cycle</td><td>1 month</td><td>1/20 man-month</td><td>6 hrs.</td></tr>
<tr><td>CORDIVEM</td><td>3 man-months</td><td>1/2 man-month</td><td>120 mins. per cycle</td><td>6 months</td><td>1 man-month</td><td>8 hrs.</td></tr>
</table>

Figure 5.2 Time Requirements Comparison of Combat Models

	Cost by Catagory				
	Data Base Acquisition	Data Base Formatting	CPU Time	Data Analysis and Evaluation	Total Cost for First 24-hours of Modeled Combat
Vector-2	19999.98		1.83	1666.67	21668.48
AWM	9999.99	833.33	50.00	833.33	11716.65
COSAGE	33333.30	66666.60	200.00 to 1800.00	33333.30	133,533.20 to 135,133.20
DIME	11666.66		400.00	166.67	12233.33
CORDIVEM	9999.99	1666.67	3600.00	3333.33	18599.99

Note: (1) Cost of CPU Time: $10.00 per min.
(2) Cost of man-month: $3333.33 per man-month ($40,000 salary)

Figure 5.3 Cost Comparison of Combat Models Excluding Player Training Cost.

CCSAGE, DIME, and CORDIVEM all consider effects of tactical fixed wing aircraft and helicopters; although, COSAGE must currently calculate these effects off-line due to problems with the tactical air module.

H. COST COMPARISON

Figure 5.2 compares the time requirements for various phases of the combat models being evaluated. The individual model cycle length[1] was included to illustrate that the man-in-the-loop model will generally use more actual time per hour of simulated combat than a closed-loop model. We also note the time requirements for CPU time and data base functions are larger for the Monte Carlo simulation (COSAGE) than the analytical simulations of combat (Vector-2, AWM).

Using Figure 4.2 as a basis, Figure 5.3 is a comparison of the cost of operation of each model. The costs are based on CPU time at $10.00 per minute[2] and manpower requirements at $3,333.33 per man-month.[3] This comparison illustrates the expenditure to model the first 24-hour day of combat. For all models, except COSAGE, the cost of each successive day will be less because the data base acquisition and formatting costs will greatly decrease. Since COSAGE is set up to input its data into (the theater level model) CEM, it is not easily used for modeling a second day of combat **[Ref. 18]**. The data output from the first day of combat must be evaluated and reformatted before initiating a second day of combat. A key assumption in COSAGE is "...modeling 24-hours of combat produces combat sample results...." **[Ref. 17: p. II-3]**, and these results are used as inputs to CEM. The

---

[1]The individual model cycle length is the number of hours of actual combat simulated per cycle of model use.

[2]Cost data for CPU time was adapted from NPS daytime cost rate.

[3]Based on $40,000 salary.

modeled within each sector and may be updated as frequently as every hour. Vector-2 does have a limited capacity for representing items to be modeled. The number of items to be represented are limited to 27 weapons types, 1 personnel type, 17 equipment types and 34 supply types for each opposing side [Ref. 29: p. 32]. This imposes a limit on the number of items for which CABF values may be generated directly.

The AWM is designed to model a MAF in combat. Terrain is modeled in a manner similar to Vector-2, but with only five levels of intervisibilty and trafficability. Weather is not considered [Ref. 30]. Amphibious warfare is modeled explicitly, since this is the primary purpose of the model. It should be noted that supply consumption is not modeled in the current version of the model [Ref. 14: p. 12].

COSAGE is designed to model an Army division in conflict with an appropriate opposing force. Terrain is modeled specifically in three groups: the Fulda group, the north German plain group, and the mixed terrain group [Ref. 17: p. III-127]. Weather (or visibility) is categorized into three separate effects in the model. Combinations of the effects are used to characterize smoke,dust,haze,fog,mist,rain,snow and illumination [Ref. 17: p. III-15]. COSAGE has no specific ability to model amphibious assault.

DIME is designed to model an Army division in conflict with an opposing army. Up to 21 different systems may be modeled on each side. Terrain and weather are both considered as battlefield modifiers. DIME has no specific ability to model amphibious assault.

CORDIVEM is designed to model an Army division or corps in conflict against an appropriate opposing force. Terrain and weather are specifically modeled while amphibious assault is not.

1. Artillery Duel Model: The Lanchester Equations are:

$$dm/dt = -(B)\,n(t) \text{ for blue, and}$$

$$dn/dt = -(A)\,m(t) \text{ for red}$$

where m(t) is the number of blue artillery pieces, n(t) is the number of red artillery pieces, A and B are the rates at which artillery pieces are lost to either suppressions or kills. The solution to the equation is:

$$m(t) = m_o(\mathrm{COSH}\sqrt{AB}t) - n_o\sqrt{B/A}\,(\mathrm{SINH}\sqrt{(AB)}\ t), \text{ and}$$

$$n(t) = n_o(\mathrm{COSH}\sqrt{AB}t) - m_o\sqrt{A/B}\,(\mathrm{SINH}\sqrt{(AB)}\ t)$$

where n_o and m_o are the initial number of artillery pieces for red and blue, respectively.

2. Attrition Due to Sea Mines: The number of landing craft and assault vehicles lost to sea mines is determined by the equation:

$$E(\text{Losses}) = N_m(1-M_{cm})(1-\mathrm{EXP}(-GW/C))$$

where N_m is the number of mines in the area,
M_{cm} is the fraction of mines cleared by mine countermeasures,
G is the number of transits through the minefield,
W is the aggregate mine damage width, and
C is the width of the minefield.

Figure 5.1 Example of Attrition Equations used in the Amphibious Assault Phase of the AWM.

G. MODEL CAPABILITIES

Vector-2 has the capability of handling theater level scenarios at the cost of aggregation to the battalion level [Ref. 13]. Vector-2 could easily handle a MAF and an appropriately sized opposing force. When modeling conflicts smaller than theater level (such as a MAF), Vector-2 has the advantage of aggregation to the company level to allow a more detailed study by the user [Ref. 29: p. 1]. Terrain and its effects are modeled by six levels of intervisibilty and six levels of trafficability. Weather conditions are

of the attrition processes in Vector-2 is thorough a includes derivation of all equations used in the model [Ref. 28: p. 51-55]. The AWM uses similar attrition processes since it is based on Vector-1. The attrition processes which were added to Vector-1 to give the model its amphibious assault phase are either Lanchester based [Ref. 14: p. 46] or expected-valued computations [Ref. 14: p. 62]. Examples of these types of attrition equations from the AWM are given in Figure 5.1 All attrition processes in the AWM are detailed in nature and well documented.

COSAGE is extremely detailed in the attrition process. In close combat, attrition is detailed to the level of the individual weapons system or item of equipment using the SSPK [Ref. 19]. All attrition processes in COSAGE are accomplished by Monte Carlo simulation.

The equipment attrition methodology in DIME is primarily detailed in nature and is based on Single Shot Kill Probability (SSKP). The general assessment equation used is:

$$K_k = \left(1 - \prod_{\text{all } i} \left(1 - SSKP_{ik} / T_k \right)^{R_{ik}} \right) * T_k \qquad (5.3)$$

where K_k is the number of kills of target type k, T_k is the number of targets of type k, $SSKP_{ik}$ is the Single Shot Kill Probability of firer i at target type k and R_{ik} is the number of rounds fired by firer i at a target of type k [Ref. 20].

CORDIVEM also relies on Lanchester methodology to model weapon system and equipment attrition. It is extremely detailed and allows the user to track losses as small as individual items loaded on a particular vehicle [Ref. 22]. The price of this extreme detail is the requirement of a large amount of computer storage, as we have seen earlier in this chapter.

inconsistency in the helicopter and tactical air modules. All five models discussed are capable of reproducing the results of a particular run when needed.

F. THE ATTRITION PROCESS

The attrition processes in Vector-2 are detailed. This detailed attrition is characteristic of the differential equation algorithms used in the model. The basic differential equations of the combat model are generally of the form

$$dn_i/dt = -\sum_j A_{ji}\, n_j \text{ for all groups } i, \qquad (5.1)$$

where t is time, n_i is the current numerical strength in weapons of the ith group of weapons, and A_{ji} is the current numerical value of the attrition coefficient for a weapon in the jth group against weapons in the ith group. Vector-2 generally solves this equation iteratively until the following end-of-battle condition is reached:

$$\Delta n_i = -\sum_j A_{ji}\, n_j\, \Delta t \qquad (5.2)$$

where Δn_i is the change in strength of weapon group i during a time increment Δt. Using the differential equation 5.1, Vector-2 attrites weapon i as a result of the fire from weapon j. Attrition continues until either a predetermined decrease (Δn) in the number of weapon i is reached or a specified amount of time (Δt) has passed. The attrition coefficient, A_{ji}, is calculated for two different types of target acquisition: serial and parallel. Serial target acquisition is modeled as a Markov renewal process. The parallel target acquisition process is based on a target priority scheme without the detection threshold schemes used in conjunction with serial acquisition. The documentation

The AWM, being primarily a Vector-1 model, is also appraised as mathematically correct by the CNA staff. Its algorithms seem to be a reasonable representation of real world attrition processes.

COSAGE, a high resolution Monte Carlo simulation of combat, has been appraised as being mathematically sound and representative of real world attrition [Ref. 18]. However, for Marine Corps use, there is the current problem of non-representative helicopter and tactical air modules [Ref. 19]. These are now modeled off-line due to unrealistic output from the model.

Due to its recent development, DIME has not undergone much appraisal of its algorithms. Its basic approach for attrition is use of Single Shot Kill Probability (SSKP) [Ref. 20], and DIME appears to realistically model real world attrition processes.

CORDIVEM has been appraised as using mathematically correct models within its many modules [Ref. 22]. Doubt exists as to the realism of the output of the model, with lack of coordination between modules within the model cited as the cause [Ref. 27].

E. MODEL CONSISTENCY

Vector-2 is analytical in nature. It produces consistent predictable results based on the inputs applied by the operator. Sensitivity analysis is easily performed due to the analytical nature of the model; therefore, allowing discussion of various viewpoints based on the assumptions.

The AWM and DIME are considered to be consistent in the results produced by the model [Refs. 16,21].

COSAGE and CORDIVEM both exhibit signs of inconsistency. CORDIVEM suffers from lack of connectivity between modules (discussed in the prior section). COSAGE suffers from

[Refs. 14,24]. Based on Vector-1, AWM is not as extensive as Vector-2 in scope, but it is transparent. Unfortunately, the AWM is used primarily for weapons systems comparisons and not for prolonged combat modeling efforts; accordingly, the model is not fully exercised by the CNA staff [Ref. 16].

The Monte Carlo simulation processes and assumptions in COSAGE are not as well documented as Vector-2 and AWM. Output from COSAGE is intended for use as an input to CEM. This restricts usage of COSAGE as an independent model since its major assumptions are geared to this role. As a "stand alone" model, COSAGE is not especially transparent.

DIME is a relatively new model which has not seen extensive use. Its assumptions and deductive processes are clearly outlined [Ref. 25]. Being a man-in-the-loop model, the deductive processes should be enhanced. The model will probably prove to be transparent once its use increases.

Originally scheduled for application in 1982, CORDIVEM bears indications of diminished transparency. Although model assumptions are clearly stated, the deductive processes within the model are not thoroughly clear. As a result, player learning time and apprenticeship for this model tends to be quite long (up to six months) [Ref. 26]. Additionally, deductive processes are not clearly implemented in the interaction between modules within the structure of the model [Ref. 27]. This would indicate the model suffers from lack of transparency in comparison to the other models considered.

D. MATHEMATICAL APPRAISAL

Vector-2 is a differential combat model and has been appraised as being mathematically sound [Ref. 15]. The algorithms of Vector-2 generally resemble a reasonable representation of real world attrition [Ref. 10: p. 71].

combat. Data for the model could be acquired, at least partially, from the existing data base for the AWM at CNA.

The Corps/Division Evaluation Model (CORDIVEM) is written in FORTRAN with some program modules in SIMSCRIPT. It is a two-sided deterministic model which requires about twenty people for operation (14 gamers, 3 staff, 3-4 controllers) **[Ref. 22]**. The model uses two VAX-11/780 computers and six additional disk drives. Large amounts of memory are dedicated to its detailed attrition processes. Approximately three and a half man-months are needed to acquire and format the necessary data. **[Ref. 13]**

Since the Marine Corps has no SIMSCRIPT complier at the present time **[Ref. 23]**, implementation of COSAGE and CORDIVEM would require acquisition of the SIMSCRIPT complier and the necessary hardware. These two models also carry a sizable manpower requirement. Vector-2 and the AWM are both closed-loop models which are written in FORTRAN, a language which can be accommodated by the AMDAHL main frame computer at Quantico. DIME is also a possible choice for implementation, but acquisition of an HP9816 or change of programming language is required.

C. MODEL TRANSPARENCY

The basic assumptions and deductive processes within Vector-2 have been well documented. The differential equations used by Vector-2 are familiar to most analysts. This indicates that Vector-2 is reasonably transparent for an experienced user. Since this model is used by several agencies (CAA, IDA, TRASANA, SAGA), alternate sources of information about the modeling assumptions and deductive processes are available **[Ref. 13]**.

The AWM is also a well documented model. Its key assumptions and deductive processes are well described

written in FORTRAN and is smaller in size and scope than Vector-2. The model is currently being used at CNA for Marine Corps related studies [Ref. 16]. Additional manpower requirements to the Marine Corps to operate AWM would be small. CNA currently employs only one full-time staff member to operate the AWM. For use in CARF generation, it is estimated that 1 or 2 people would be be required for operation. CNA maintains current data for model usage and uses its own computer (a VAX unit) for execution of the model. The AWM is compatible with Marine Corps computer assets.

The COSAGE model is used at the Concepts Analysis Agency (CAA) as part of the WARRAMPS methodology. It is written in SIMCRIPT II.5 programming language and is currently executed on a UNIVAC 1100/82. CAA maintains a staff of 10-14 personnel to maintain and execute the model and its extensive data base. Marine Corps use would necessitate a staff of approximately the same size. Data requirements for the model are extensive, up to 30 man-months are required to acquire and format the necessary inputs. The Marine Corps has no source of data for COSAGE other than data available from CAA. Basically a Monte Carlo simulation, COSAGE requires large amounts of computer time to complete a 24-hour day of combat (up to 180 minutes). [Refs. 17-19]

The Division Map Exercise (DIME) is a two-sided, computer assisted, open map exercise. It is written in HP Basic and operates on a Hewlett Packard (HP) 9816 mini-computer with a hard disk storage device and a printer [Ref. 20]. About six people (4 players and 2 controllers) are needed to operate the model. The data base initially requires about three man-months to acquire [Ref. 21]. Since DIME is a man-in-the-loop war game, the time to complete a cycle is significantly longer than a closed-loop model. Over 24 hours of "play" are needed to simulate a (24-hour) day of

TABLE 4

Causes of Attrition Considered by Model

Cause of Loss	Category of Loss		
	Material in Hands of Combat Units	Material in Storage or Maintenance in Theater	Material in Transit
Direct Fire	ABCDE		
Area Fire	ABCDE	ABCE	B
Rocket launcher Fire	ABCDE	ABCE	
Air attack	ABCDE	ABCE	
Damaged and Abandonment			
Land Mines	ABCDE		
Mobility Failure and Abandonment			
In Maint. and Abandonment			
Accident			
Wear-out	C		
Missiles	ABCDE	ABCE	B
Sabotage and Guerilla Activity			
Pilferage			
Reallocation to Allies or other Service	ABCDE	ABCE	
Sea attack			B

Legend: A = Vector-2
B = AWM
C = COSAGE
D = DIME
E = CORDIVEM

typically varies from twenty to eighty kilometers from the FEBA depending on the capability of the model and the scenario. Attrition at greater depths must be accomplished by other means. COSAGE does possess the capacity to model weapons system wear out. A typical example is wear of the tube on an artillery piece. If the tube wears out, the artillery piece is removed from combat until maintenance is completed [Ref. 3: p. 47]. Reallocation of equipment to other services or allies is accomplished through the logistics and supply inputs in each of the models.

B. SOME PRACTICAL CONSIDERATIONS

Manpower requirements for Vector-2 are variable depending on the frequency and intensity of use. Once the several decision modules contained in the model have been adapted to Marine Corps doctrine, the data input and operation of the model would proceed rapidly [Ref. 15]. For Marine Corps use, we can estimate 2 to 3 people are needed to operate the model once the decision logic is in place. Although six man-months are required for initial data base acquisition and formation, this time is greatly reduced in subsequent usage since the input data changes very little [Ref. 15]. Vector-2 could be managed by analysts currently available in the Marine Corps. Data for Marine Corps usage of Vector-2 could be obtained from data bases at CNA or the JCS, a user of Vector-2. Since Vector-2 is written in ANSI FORTRAN, the computers available for Marine Corps' use should be adequate. The model needs a minimum of 120K storage to function [Ref. 13]. Extensive use of a large data base would preclude use of a mini-computer and dictate utilization of the AMDAHL mainframe computer at Quantico.

The Amphibious Warfare Model (AWM) is an adoption of Vector-1 (Vector-1 is the predecessor of Vector-2). AWM is

TABLE 5

Cost Comparison of Combat Models Including Player Training Cost

Model	Total Cost for the First Day (24-hours) of Modeled Combat With One Group of Trained Players	Total Cost for the First Day (24-hours) of Modeled Combat With Shifts of Trained Players for 30-Days of Model Operation
Vector-2	$ 21,668.48	$ 21,668.48
AWM	$ 11,716.65	$ 11,716.65
COSAGE	$ 133,533.20 to $ 135,133.20	$ 133,533.20 to $ 135,133.20
DIME	$ 25,566.65	$ 65,566.61
CORDIVEM	& 65,266.61	$ 158,599.85

takes much less than a working day (8-hours) to complete a day of simulated combat. The resulting inaccuracy will not detract from our model comparison since the closed-loop models will tend to have much lower operational costs than the man-in-the-loop models. Man-in-the-loop models (DIME, CORDIVEM) must be operated on a 24-hour a day basis to achieve a simulated combat day within 24-hours. An adjustment factor for the number of shifts needed in a day is applied in Table 6 to adjust for this problem. The adjustment factor is the number of shifts of players needed to operate a man-in-the-loop model continuously (24 hours a day). We also need to compensate for the number of shifts which must be trained to operate a man-in-the-loop model continuously for thirty days (4 shifts for DIME, 3 for

TABLE 6

Daily Operational Costs of the Combat Models

	Vector-2	AWM	COSAGE	DIME	CORDIVEM
Number of operators/players	3	1	10	6	20
Number of shifts per day to run a man-in-the-loop model continuously	N/A	N/A	N/A	4	3
Cost per man-day	111.11	111.11	111.11	111.11	111.11
Total cost of operators/players	333.33	111.11	3333.33	2666.64	6666.60
CPU time per combat day (in minutes)	0.1833	5	20 to 180	40	360
Cost per CPU minute	10.00	10.00	10.00	10.00	10.00
Total cost of CPU time (in dollars)	1.83	50	200 to 1800	400	3600
Total daily operational cost (in dollars)	335.16	161.11	3533.33 to 5133.33	3066.64	10266.60

Note: Cost per man-day is based on a $40,000 salary and a 360-day year.

CORDIVEM). Since this is a training cost incurred before the first day of model operation, we will add this cost to the the last column of Figure 5.3 to find the cost of the first day of modeled combat adjusted for shifts of trained players. The last column of Table 5 displays the cost of the first day of modeled combat adjusted for the cost of the required number of shifts of trained players. Using the data from the last column of Table 5 (as y-intercept) and Table 6 (as slope), we can graphically compare the cost to operate the models for 30 days of simulated combat for a given scenario. Although these are approximate costs, Figure 5.4 is helpful for comparison of the models. Figure 5.4 shows that COSAGE, CORDIVEM and DIME have greater daily operational costs (from the slope) than Vector-2 and AWM. Since this is a high cost estimate for these two models, we can say the closed-loop model (such as AWM or Vector-2) is more economical than a man-in-the-loop model for the purpose of CARF generation.

We have compared five combat models on the basis of criteria derived in earlier chapters. Each of the models exhibit strengths and weaknesses when reviewed for the purposes of CARF generation. In the final chapter, we will draw conclusions as to which models are best suited for CARF generation and make recommendations for further action.

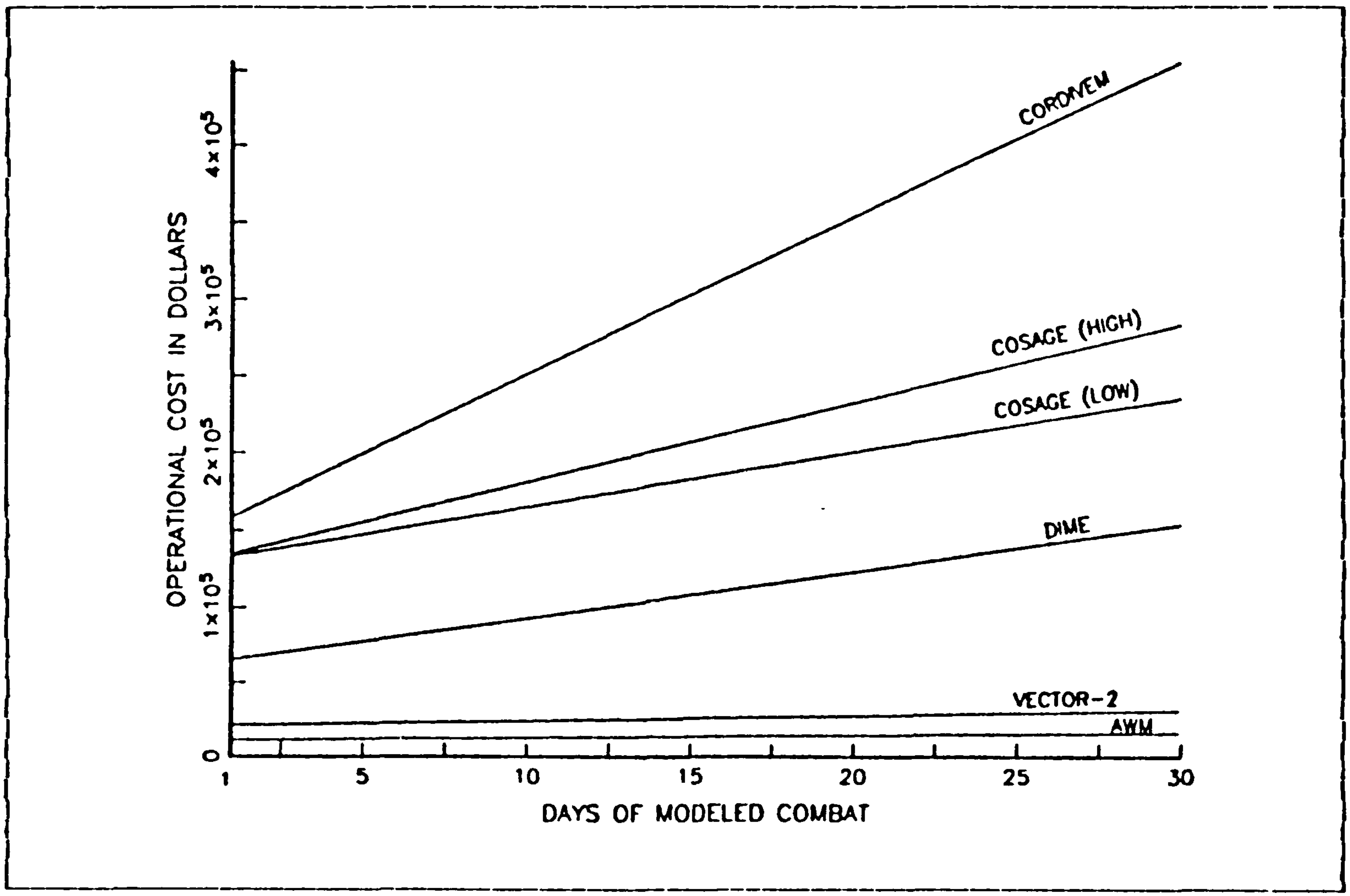


Figure 5.4 Operational Cost Comparison of Combat Models

VI. CONCLUSIONS AND RECOMMENDATIONS

We have surveyed five combat models for the purpose of generating CARF values. In this chapter, we will make observations and conclusions as to which models are best suited for this purpose. We will follow the conclusions with recommendations for further study.

A. CONCLUSIONS

For the purpose of CARF generation, man-in-the-loop models (such as DIME and CORDIVEM) exhibit two distinct disadvantages. First, these models generally take longer to complete a full (24-hour) day of combat than a closed-loop model (such as COSAGE, AWM or Vector-2). For instance, we would need to operate the DIME continuously for at least thirty calender days to obtain thirty days of simulated combat data for use in generating a CARF for one version of a particular scenario. The closed-loop model (such as Vector-2) would complete several versions of a particular scenario within thirty days. This is a great advantage when accurate CARF estimates are needed on short notice or several possible variations within a particular scenario must be analyzed. Secondly, the man-in-the-loop model requires trained players; the closed-loop model does not. As discussed in the previous chapter, this creates additional expense in operating the model. Each player must complete a training period (both DIME and CORDIVEM require at least one month per player) before he is useful in the modeling process.

Training time and playing time are an expensive commodity which can be avoided by the use of closed-loop

models. Unless the CARF generation process is combined with some type of tactical training or schooling, there is no need for the added expense and time created by using a man-in-the-loop model. Table 7 illustrates the time required to complete thirty days of simulated combat and the number of operators and players needed for each combat model.

TABLE 7

Comparison of Time and Personnel Requirements for the Combat Models

Model	Time to Complete 30 days of Simulated Combat	Number of Operators and Players
Vector-2	5.5 minutes	approx. 3
AWM	150 minutes	1 to 2
COSAGE	10 to 90 days	10 to 14
DIME	30 days (see note)	6
CORDIVEM	30 days (see note)	20

Note: DIME and CORDIVEM would require 30 days only if the model were operated on a 24-hour a day basis continuously for 30 days.

The speed with which a closed-loop model operates enables the user to evaluate alternate versions of a specific scenario. This is particularly true of analytical models (such as AWM and Vector-2) which are faster than a Monte Carlo simulation (e.g. COSAGE). COSAGE would also be difficult to adapt for CARF generation since it is designed

to produce only one day of combat as input to CEM (noted in Chapter V). Vector-2 and the AWM have the added benefit that no additional computer hardware or software is needed for Marine Corps use. This is not true of COSAGE, DIME, and CORDIVEM.

Evaluation of the AWM and Vector-2 in Chapter V revealed that these two models are particularly well suited to CARF generation. Both are closed-loop models and analytical in nature. AWM and Vector-2 are not staff intensive and neither bears the current consistency problems common to COSAGE and CORDIVEM. Vector-2 is probably a better choice for a CARF generation system since it models weather and is generally considered more sophisticated than the AWM. AWM does not specifically model the effect of weather (a restriction inherited from Vector-1).

As with any model adapted to generation of CARF values, Vector-2 must be scrutinized to modify its internal decision modules to reflect Marine Corps doctrine. Once this is accomplished, the data base may be taken, in part, from the AWM since much of the data required for both models is similar. Vector-2 also has potential for using the amphibious phase of the AWM, if amphibious assault must be modeled within a scenario.

B. RECOMMENDATIONS

As a result of the study of CARF generation, we can make four recommendations. First, the current system of generating CARF values through conversion of Army WARF values could be improved by using a basic combat model such as Vector-2. Secondly, procedures for selecting items for which CARF values are to be generated should be reviewed. An item may be assigned a CARF value as a result of its physical relationship to another item (i.e. the CARF for

tank tracks will depend on the CARF for tanks). Thirdly, since the CARF is used primarily in the budgeting process, particularly expensive items should be monitored closely during CARF generation. Budgeting for such items depends upon the accuracy of the CARF values generated. These items, as well as items which involve scarce resources or long manufacturing lead times, should be designated as "critical items" to be specifically monitored within a CARF generation process. Lastly, additional means of estimating equipment losses must be used to supply attrition estimates for those causes of attrition not considered by Vector-2. These causes of attrition are evident from comparison of Table 2 and Table 4 . These estimates may be the result of historical data, exercise data, military judgment, or other modeling efforts.

It is hoped that this survey of combat models for use in CARF generation will be helpful to those who conduct further work in this problem area.

APPENDIX A

A BRIEF OVERVIEW OF THE CURRENT CARF DETERMINATION SYSTEM

Figure A.1 is a schematic of the four major modules of the current CARF Determination System. Explanation of the system will proceed in order of the four major modules as marked in the figure.

A. THE WARF EXTRACTION MODULE

The WARF extraction module extracts from the Army's WARF data tape the necessary Line Item Numbers (LIN) for the entire process. The process of deriving the WARF will be explained later in Appendix B.

B. THE CARF REFERENCE DATA FILE (CRDF) UPDATE MODULE

The CRDF update completes a Table of Authorized Material Control Number (TAMCN) and LIN cross reference as well as recording the assigned equipment category codes. Three programs are used to maintain the CRDF.

1. The CRDF LIN Validation Program

The LIN validation program matches a new WARF Extract File against the CRDF and reports the two following conditions: first, any new LIN on the WARF tape and secondly, any LIN deleted from the WARF tape.

2. The CRDF TAMCN Validation Program

The TAMCN Validation Program matches the Item Data File (IDF) against the CRDF to report the three following conditions: any new TAMCN, any deleted TAMCN and any CRDF records without valid equipment category codes.

3. The CRDF Update Program

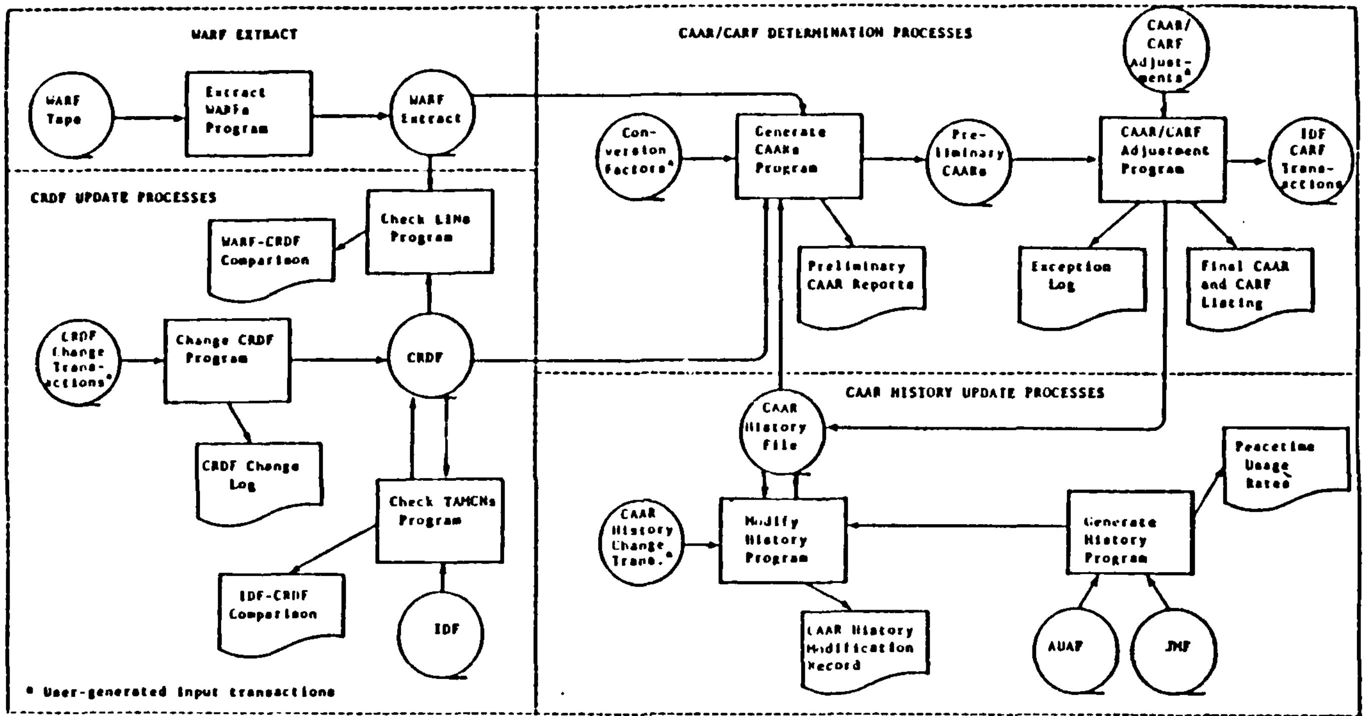
The CRDF Update Program enables the user to manually delete CRDF records, add records or change individual fields within records.

C. THE CAAR/CARF DETERMINATION PROGRAM

The CAAR/CARF Determination Program processes user generated CAAR/CARF adjustments against previously created preliminary CAARs. Final CAARs are recorded on the CAAR history file and CARF transactions are placed in a data-set to be used to update the IDF.

D. THE CAAR HISTORY UPDATE MODULE

The CAAR History Update Module provides for the collection of equipment attrition data not only from the CAAR/CARF determination process, but from studies, exercises, simulations, peacetime usage, combat history and other such events. This program does provide a data collection capability not enjoyed until the adoption of this system. Any further questions can be answered by Reference 6 .



Note: The magnetic tape symbol is used for all files depicted in this chart. However, it is recognized that, depending upon frequency of use, some files may be stored on discs.

Figure A.1 Overview of the Current CARF Generation Process

APPENDIX B

AN OVERVIEW OF THE GENERATION OF A WARTIME ACTIVE REPLACEMENT FACTOR (WARF)

Since we have already seen how the CARF is generated, we must determine how the basis of the CARF determination system is produced. The WARF (the adopted parent of CARF), is one of three outputs of the U.S. Army Wartime Requirements for Ammunition, Material and Personnel System (WARRAMPS). The WARF is defined as the average daily catastrophic (non-reparable) item loss rate expressed as a percent of the average authorized item strength in the combat theater. The WARF differs from the CARF in that it is expressed as the average daily loss rate vice a 30-day rate. Unlike the CARF, which is expressed for the 30-day period, the WARF is computed for several periods of different lengths all adding to 180 days. The time increments are two 15-day periods followed by five 30-day periods.

The mission of WARRAMPS is to simulate future conflicts using a specified weapons system and force-mix in an Army specified theater of operations against a predetermined threat. The output of WARRAMP is inclusive of the entire theater over the duration of combat operations and specifies the ammunition expended (by DODIC), the material destroyed (by LIN), and the personnel killed or wounded (by MOS).

We are interested in the output of material destroyed which leads to the determination of WARFs. The WARRAMPS consists of a hierarchy of models comprising the following four major parts:

1. Preprocessers,
2. Combat Sample Generator Model (COSAGE),
3. The Concepts Evaluation Model (CEM), and
4. Postprocessers.

The system also allows for the input of Army doctrine regarding battlefield deployment of the friendly and enemy forces along with enemy tactical doctrine.

A. THE PREPROCESSER

The preprocesser component consists of the preliminary inputs required to operate the COSAGE model. These inputs require considerable resources to prepare. About ten man-months are required for the technical data base while thirty man-months are required for the force definition data and analysis.

B. THE COMBAT SAMPLE GENERATOR (COSAGE) MODEL

COSAGE is a high resolution model which creates a "stylized day" of combat for the theater given the data set. Stylized day simply means that the model runs a 24-hour period of simulated combat and produces a "typical combat day". One should remember that while COSAGE is a high resolution division size model (with corresponding red force) which resolves as low as the platoon level (with corresponding red force), it does so for only one 24-hour period.

C. THE CONCEPTS EVALUATION MODEL (CEM)

The 24-hour "stylized day" of combat output (produced by COSAGE) is utilized in the next stage by the Concepts Evaluation Model (CEM). The CEM is a low resolution, fully automated war-gaming model that expands the output of COSAGE across the whole theater of operation. Characteristics of CEM include:

--theater wide,
--fully automated,
--deterministic,
--resolves to: battalions, several hundred sectors,
--time phased using 12-hour steps,
--controlled by simulated commander's decision, and
--sensitive to design-important force characteristics.

The output from CEM is quite detailed and includes:

--FEBA location and movement,
--unit mission, location, boundaries and status,
--on-hand personnel, major weapons supplies,
--artillery ammunition consumption,
--battalion engagement frequencies,
--force ratio engagement type, and
--fighter-aircraft availability, allocation and losses.

D. THE POSTPROCESSERS

The fourth major component of the WARRAMP system are the postprocessers which transforms output of COSAGE, CEM and historical data into WARFs. The principal model used in this process is Equipment Loss Consolidater (ELCON). It should be noted that ELCON is essentially a bookkeeping routine, while COSAGE and CEM perform the actual attrition processes. Direct fire weapons and activities are attrited primarily by CEM, while losses of items not normally engaged in direct fire activities such as motor vehicles, engineer equipment and radar are computed through Army historical data and COSAGE output. Losses for extraneous reasons (such as wear out, pilferage, guerilla activity) are obtained primarily from Army historical data. Figure B.1 presents an overview of WARRAMPS. [Ref. 4]

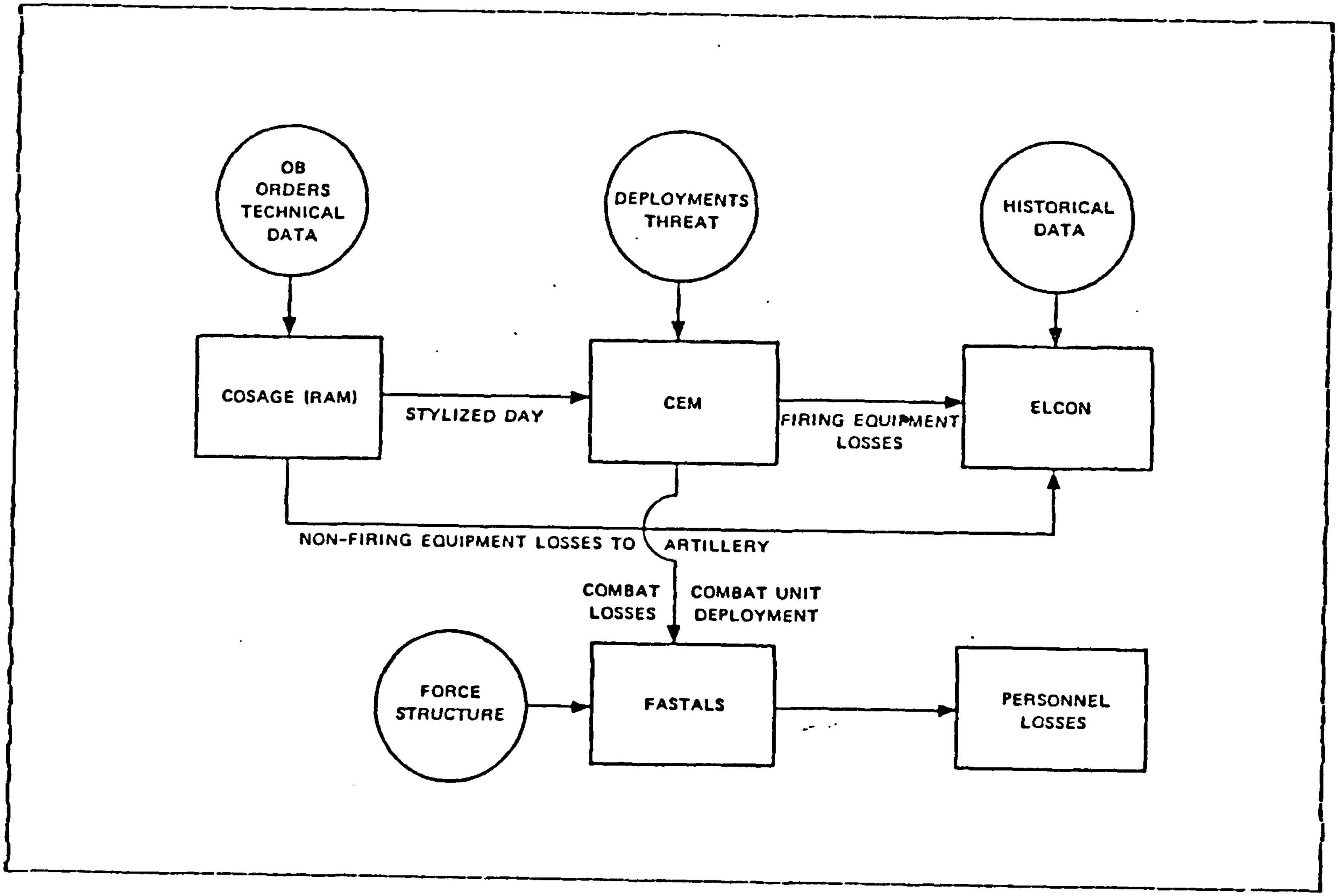


Figure B.1 Overview of WARRAMPS Data Flow

APPENDIX C

POINTS OF CONTACT FOR THE COMBAT MODELS SURVEYED

(1) Vector-2: Command and Control Technical Center
C315
The Pentagon
Washington, D.C. 20301
Telephone: 695-3521

(2) AWM: Mr. Stephen Gates
Center for Naval Analysis
2000 North Beauregard Street
Alexandria, Virginia 22311
Autovon: 225-9241, ext.3807

(3) COSAGE: Mr. Charles A. Bruce Jr.
US Army Concepts Analysis Agency
8120 Woodmont Avenue
Bethesda, Maryland 20814
Autovon: 295-5258

(4) DIME: Mr. Kent Pickett
US Army Combined Arms Operations Research Agency
Fort Leavenworth, Kansas 66027-5230
Autovon: 552-5511

(5) CORDIVEM: Mr. T. Bailey
US Army Combined Arms Studies and Analysis Activity (ATZL-CAR-MD)
Fort Leavenworth, Kansas 66027-5230
Telephone: (913) 684-5176

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20. Conversation with LtCol. C. Macchiaroli (USA), US Army TRADOC Research Element Monterey (TREM), Monterey, California, 15 October 1984.

21. Telephone Conversation with Mr. Kent Pickett, US Army Combined Arms Operations Research Activity (CAORA), Fort Leavenworth, Kansas, 21 January 1985.

22. Telephone Conversation between LtCol. Wiseman (USA), US Army Combined Arms Operations Research Activity (CAORA), Fort Leavenworth, Kansas, and Major I. Keller (USA), US Army TRADOC Research Element Monterey (TREM), Monterey, California, 25 January 1985.

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